UNIVERSITY OF NAIROBI

USE OF EXPANDED POLYSTYRENE AS A SOLUTION TO LOW COST HOUSING IN KENYA

By

GITHUKU LILIAN KAGENI

F16/29423/2009

A project submitted as a partial fulfilment for the requirement for the award of the degree of

BACHELOR OF SCIENCE IN CIVIL AND CONSTRUCTION ENGINEERING

2014

Abstract

Demand for housing in Kenya is growing faster than the supply by developers, increasing the housing deficit in the country. This project addresses this problem by carrying out an intensive research and field study on using expanded polystyrene as an alternative building material that may be used for low cost housing in Kenya. The objective of this project is to evaluate the mechanical properties of expanded polystyrene and its suitability for its use as building material, as well as the cost of using the technology to build houses as opposed to the conventional masonry method.

A case study of panels from the National Housing and Corporation (NHC) will be used to evaluate the cost of using the technology as a building construction material. Research shall be carried out through interviews and questionnaires; these will help gain better understanding of the technology. Supporting information will then be sought and used to assess suitability of using the technology as well as verify whether it can be used as a low cost solution.

The main findings are that the expanded polystyrene panels manufactured at NHC have minimal compressive and flexural strength, hence mainly act as a filler material in the structural system, offering high bending stiffness for a low density, to structural members. It was also found that the material cost for building using the expanded polystyrene technology was greater than the quarried stones for building a wall. Although due to the labour intensive process that masonry work requires, the conventional method was more expensive on labour than the expanded polystyrene technology. Hence the technology offers a way of meeting the housing demand at a total lower cost.

Dedication

To God, to my parents, my brother and sister who have accorded me with endless support during my undergraduate studies, to my lecturers in the department of civil and construction engineering for the knowledge they have imparted in me in my undergraduate studies from whom I have learnt so much, God bless you all.

Acknowledgement

I sincerely appreciate Dr. S. Mumenya, my project supervisor and lecturer in the Department of Civil and Construction Engineering, University of Nairobi, for her continued guidance, support and helpful suggestions on the project work.

Thanks to Eng. Mwagangi and Eng. Munene of NHC factory for welcoming me to the factory during my research period and providing me with some literature materials. I also thank Mr. Menelik K. Makonnen of NASCA Construction Limited, Eng. Pius Kiprotich and Mr. Pius Omullo of NHC, for your patience, support and advice during the data collection process and for literature materials.

I thank God for keeping me healthy during the project period and also for insight in what I was undertaking. Last but not least, to my parents for both financial and moral support.

God bless you all.

Table of Contents

Chapter One 7

Introduction 7

1.1 Problem Statement 8

1.2 Justification 8

1.3 Hypothesis 9

1.4 Objectives 9

1.4.1 Specific Objectives 10

Chapter Two 11

Literature Review 11

2.1 General 11

2.2 Background 12

2.3 Raw Material 13

2.4 Manufacturing Process 14

2.5 Structural Elements of the System 16

2.6 Comparison of Construction Methods 25

2.7 Expected Strength Required for Panels 30

Chapter Three 31

Methodology 31

3.1 Introduction 31

3.2 Data Collection Methods 31

3.3 Description of Questionnaires 32

3.4 Test Procedures 35

3.5 Compressive Strength 36

3.6 Flexural Strength 36

Chapter Four 39

Results 39

4.1 Introduction 39

4.2 Test Results 40

4.3 Cost Analysis 40

Chapter Five 43

Discussion 43

Chapter Six 45

Conclusion and Recommendation 45

6.1 Conclusion 45

6.2 Recommendations... 46

References..47

Appendices...50

Chapter One

Introduction

In 1976, the International Labour Organisation's World Employment Conference introduced the "basic needs" approach as one that attempts to define the absolute minimum resources necessary for long-term physical well-being of a human being. The list of immediate "basic needs" is food, water, clothing and **shelter**. [1]

Kenya has one of the world's highest rates of population growth. A census conducted in 2009 revealed Kenya's population to be 38.6 million compared to 28.7 million in 1999. The population growth has been estimated at 2.7% as of 2010 which resulted in an estimation of total population of 41 million in 2011. [2] Almost half of the country's population lives below the poverty line, with a quarter of the population living in urban areas. [3] From the statistics, Kenya can be characterised by a quickly growing population, rapid urbanisation and rising urban poverty.

Today, the demand for home ownership in Kenya has risen due to steady population growth and consequently in Nairobi due to rural to urban migration. Kenya is experiencing a very high housing deficit due to lack of housing for the middle and more importantly, low income earners. The growth of urban poverty in Kenya presents a key development challenge for the country. Housing is out of reach for many Kenyans. This has led to the introduction and high growth in informal settlement also known as 'slums' such as Kibera and Mathare in Nairobi which are commonly known as a breeding places for diseases, crime and other social ills. [4] About 55 per cent of urban residents currently live in poverty in slum settlements [5] (characteristics of a slum are high density and low standards of housing). This is as a result of a major shortage of decent homes for the middle and low income earners.

There is an average shortage in annual supply of housing. This has doubled to 400,000 units [6] since the last real estate census which was conducted three decades ago. [6] Only 50,000 housing units are supplied every year as the country urbanises. [7] The national housing deficit is high due to a lag in supply of homes in comparison to population growth.

1.1 Problem Statement

A major weakness with the Kenyan government over the years is the failure to provide adequate and affordable housing to meet the needs of the rapidly rising population in Kenya, with keen interest in urban areas due to rise in population caused by rural to urban migration. Many Kenyan citizens are migrating from the rural areas to urban areas in search of education and job opportunities. This results in a large number of them ending up with no place to live hence settling in either slums or perhaps ending up homeless.

In Nairobi, with a population of around three million people, 73 per cent of whom live below the poverty line, nearly 60 per cent of houses are considered 'inadequate' and are located in slums. [8] The lowest cost of a house unit is Sh4.5 million, which majority of the people cannot afford. [9]

Factors that have increased housing deficit in Kenya include:

I. Majority of the developers in Kenya are putting up high end properties that are only attainable by a few members of the society.
II. High mortgage rates by commercial banks which has led to low intake of mortgages because most Kenyans cannot afford mortgages at their current rates.
III. In the past 10 years, land prices in some parts of Nairobi have risen by nearly 1,000 per cent. [8] The cost of land significantly influences the cost of a house, hampering growth of low-income housing.
IV. Building codes that do not include a range of building materials cheaper than the tradition brick and mortar. The cost of building materials in a normal construction will take up to 65 per cent of the overall cost (the rest is spilt into 30 per cent for labour and 5 per cent for plant). [10]

1.2 Justification

In engineering, the best way to solve the rising housing deficit in the country is by considering cheaper and better ways of building that will reduce the 65 and 30 per cent of overall costs brought about by building materials and labour respectively. Materials represent a major expense in the overall cost of a construction project. Minimizing procurement costs presents important prospects for reducing costs. A 5% rise in labour costs could increase the cost of construction project by 1.5%. [10]

Construction using prefabricated materials is a relatively new method in Kenya, to get buildings up fast. Parts of the building are pre-made in the factories in order to cut down on construction time, labour, and lower the overall cost of a project.

Expanded Polystyrene (EPS) is a lightweight cellular plastic material consisting of small hollow spherical balls. It is an incredibly flexible material that is widely used for building and construction products. The technology has been found to be cheaper than the conventional method of construction using brick and mortar. The products consist of lightweight foam blocks made of EPS which are cut into panels (single or double depending on design requirements) prefabricated in the factory, and are stacked together to make up the desired wall shapes which are then coated with cement mix or filled with concrete. These materials are used to build single level and multilevel walls, slabs, retaining walls and underfloor insulation panels for heating, cooling and sound insulation. EPS is a cost effective material for thermal and sound insulation.

As the Kenyan population increases and with the existing housing deficit and a lag of 350,000 houses annually, the Kenyan Construction Industry is now realising the potential of EPS as a preferred long term solution to the increasingly demanding national housing deficit.

1.3 Hypothesis

Expanded polystyrene construction technology provides a low cost solution to the national housing deficit in the country.

1.4 Objectives

1. To evaluate the suitability of using expanded polystyrene technology in construction as a possible solution for low cost housing
2. To evaluate cost of using expanded polystyrene as a construction material.

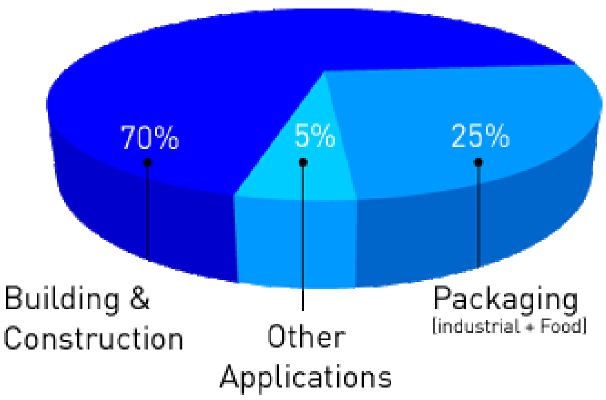
1.4.1 Specific Objectives

1. Research tests carried out for compressive strength and flexural strength of load bearing units.
2. To review similarities and differences of the expanded polystyrene technology as compared to the traditional stone and mortar method of construction.
3. Form questionnaires for use of inquiring contractors, engineers and quantity surveyors about extensive use of EPS in the country as well as cost of purchasing the EPS and workmanship costs.

Literature Review

2.1 General

EPS is one of the biggest commodity polymers produced in the world. It is a rigid foam with a unique combination of characteristics such as its lightweight, good thermal insulation, strong absorption of shock, high compressive strength and good moisture resistance. EPS is used in many applications like food packaging, cushioning of valuable goods, and as panels for buildings and other construction.



[11]

Figure 2.1 Chart of EPS applications

In engineering, EPS is used in the building and construction industry and huge quantities are utilized to make insulation foam for walls, roofs and floor insulation. EPS has also found uses in road construction, bridges, swimming pools, retaining walls, basements and construction of sound proof rooms.

EPS panels are part of prefabricated construction. In this process, only the foundation is constructed in the traditional method of stone and mortar, while the sections of walls, floors and roof are prefabricated and assembled in a factory, then transported to the site, put in place and cemented together.

Advantages of prefabrication:-

i. It is a fast method of construction hence reduces construction time
ii. Cost effective
iii. Environmentally friendly
iv. Reduction on construction waste
v. It is precise
vi. Set standards can be adhered to easily
vii. Applicable for mass construction
viii. Reduction in number of labourers

Disadvantages of prefabrication

i. Leaks can form at joints in prefabricated components
ii. Jobs may be lost due to reduced number of labourers required
iii. Need for specialized equipment

2.2 Background

In 1967, Werner Gregori patented the first Insulated Concrete Form (ICF), (commonly known as EPS here in Kenya) in North America. Initially, each block measured about 406mm by 1219mm. [12] Although initially hampered by lack of awareness and building codes, ICF has since then, experienced a spread in use of the technology from Canada to Italy, to South Africa and consequently, to here in Kenya. EPS was first used in Kenya in 2004 - this is the year the government approved its use. Panels were imported from South Africa and Dubai to build houses in Muthaiga. [13] The technology is adapted differently in different countries due to geographical climate.

In Kenya, construction of houses using the EPS technology is by assembling ready-made EPS foam, sandwiched between galvanised steel wire mesh that is plastered on both sides with concrete. On average, one would need 70 panels each weighing 15 kilograms to build a standard two-bedroom house measuring around 100 square meters. This means that an entire house can be carried in a single lorry load. Houses built using the EPS technology are strong enough to withstand natural calamities even better than houses built using the conventional building materials, despite their low weight. EPS panels can be used to build up to 20 storeys. [14]

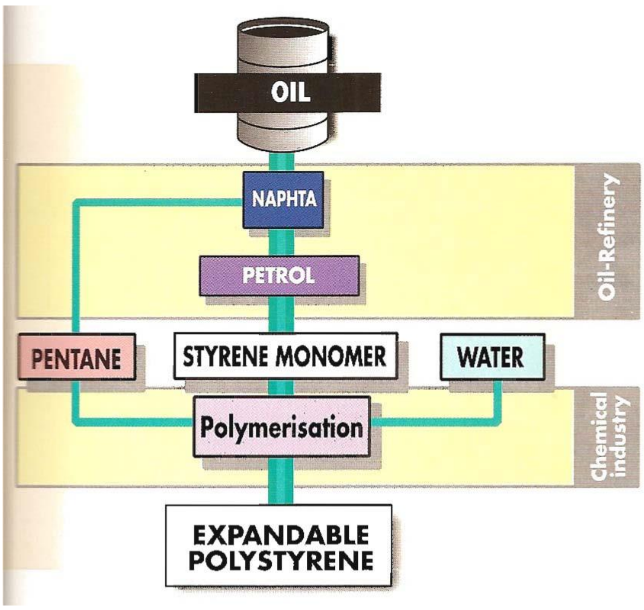
In November 2013 the National Housing Corporation (NHC) EPS factory was opened in Mavoko for the mass production of self-extinguishing EPS panels. Andrew Saisi, the General Manager of NHC's EPS factory, claims that the technology will lower construction costs by 30 per cent as well as reduce the time taken to house by 50 per cent. [14]

The NHC EPS factory has an annual capacity of producing on average 210,000 panels, enough to build about 3,000 housing units of 100 square meters. [15]

Despite the EPS technology being adopted by NHC, the factory will not be able to supply the capacity needed to cover the lag of 350,000 housing units. But it will be a step in the right direction of building affordable, low cost housing to cater for the middle and especially lower class earners. Consistent growth in the building and construction industry, will help further expand the EPS market.

2.3 Raw Material

EPS is made from styrene, a by-product of crude oil extraction. It is also found in the natural starch contained in many fruit such as strawberries and food products such as wine coffee beans and cinnamon.



[16]

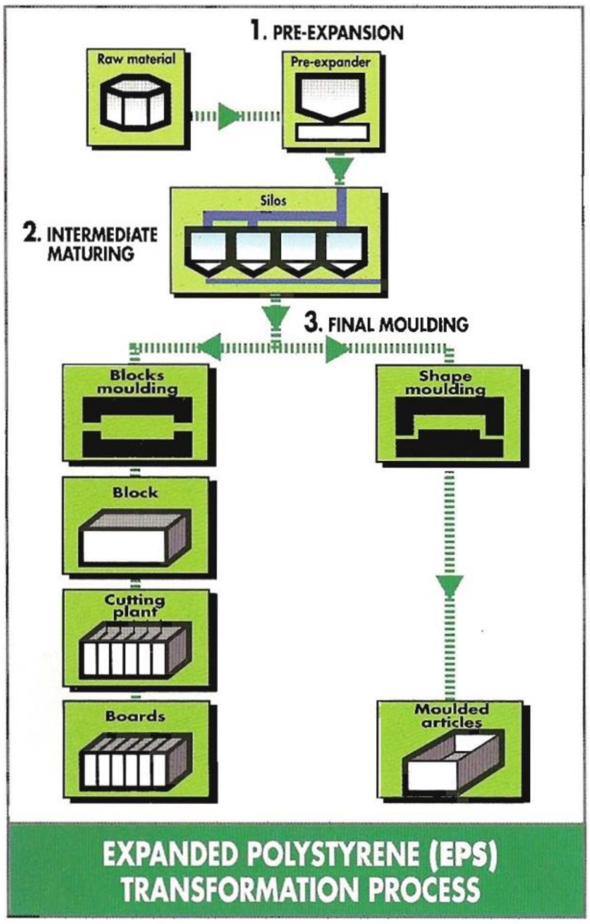
Figure 2.2

EPS is a derivative of ethylene and benzene and is made using a polymerization process which produces translucent spherical beads of polystyrene with sizes ranging from 0.5 to 1.3mm [17] in diameter. During this process a low boiling point hydrocarbon usually pentane gas, is impregnated to the material.

Pentane has a Global Warming Potential (GWP) of zero. The European Union does not register pentane as substance hazardous to human health or the environment. [18]

2.4 Manufacturing Process

Manufacturing process is carried out in three stages:



[18]

Figure 2.3

1^{st} Stage – Pre-Expansion

The raw material (beads) are heated in special machines called pre-expanders with steam introduced to the vessel at temperatures of approximately 100^{0}C. [16] The steam causes the pentane to be released from the beads. During the process of pre-expansion the beads swell up to almost 50 times their original size. Once the desired volume has been reached, the expanded beads are released into a bed dryer and all condensed steam moisture is dried from the surface. This process takes approximately 3 min to finish.

Figure 2.3.1 Raw material beads

Figure 2.3.2 Expanded beads

2^{nd} Stage – INTERMEDIATE MATURING

Once the expanded beads have been dried, they are blown into large open silos or mesh bags for the aging process. This is because on cooling, the expanded beads form a vacuum in their interior which must be equalized to atmospheric pressure to prevent collapse or implosion of the beads. Hence this process allows the beads to fill back up with air. This process can take from 12 hours to 48 hours in order to achieve a greater mechanical elasticity and improve expansion capacity of the beads and also depends on the desired expanded density required of the beads.

Figure 2.3.3 Silos

3rd Stage – FINAL MOULDING	
In this stage, the pre-expanded beads are transported to moulds where they are further subjected to steam so that as the beads are compressed, they bind together to form a block "block moulding" – that are later cut into panels and shaped – or products are moulded in their final finished shape "shape moulding".	 Figure 2.3.4 Foam blocks

EPS manufacturing units do not produce solid waste from the production process. All process waste or off cuts, is recycled into the production process.

2.5 Structural Elements of the System

The concrewalls system is composed by panels consisting of polystyrene sheet assembled together with welded wire mesh. The panels are finished on site by pouring concrete (double panel, floors, stairs) and spraying shotcrete (single panel).

2.5.1 Single Panel

2.5.1.1 Load Bearing Wall

Used in buildings up to 3-4 storeys. Panels are finished on site by structural shotcrete in both sides.

The EPS sheet is 1200mm wide and 50-160mm thick with a wave length of 15mm and a density of 10-15 Kg/m^3. The mesh is made from galvanised steel with a stress tension value of up to 700 N/mm^2. The mesh width is 1235mm with longitudinal and traverse wires with a diameter of 2.5-3mm. The longitudinal wire step is 80mm and traverse step is 75mm. The mesh wire connectors have a diameter of 3mm and step of 150mm. The structural plaster should be 35mm thick on both sides with a performance value of $\geq$ 25 N/mm^2.

Figure 2.4

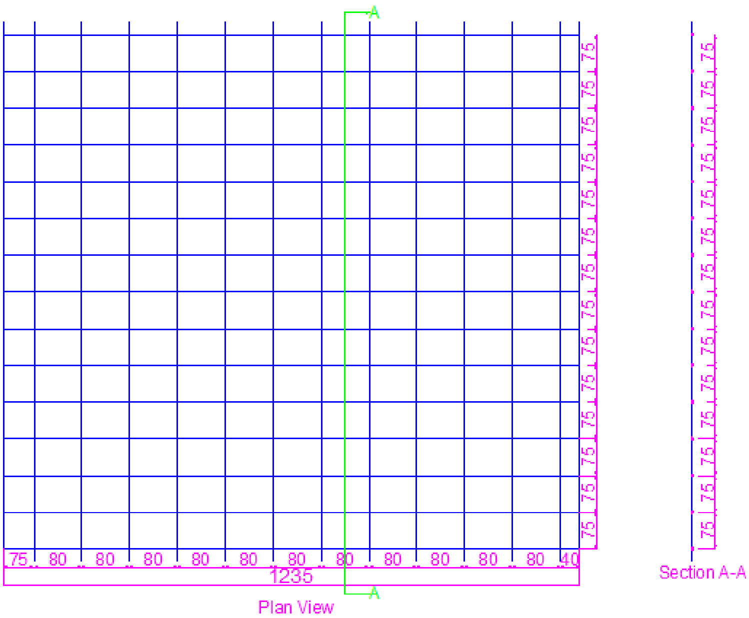


Figure 2.5

2.5.1.2 Partition and Cladding Wall

Used in buildings with structures made in panel or traditional system. Panels are finished on site by cement plaster on both sides.

The EPS sheet is 1200mm wide and 40-280mm thick with a wave length of 5mm and a density of 10-15 Kg/m^3. The mesh is made from galvanised steel with a stress tension value of up to 700 N/mm^2. The mesh is 1235mm wide with longitudinal and traverse wires with a diameter of 2.5-3mm. the longitudinal wire step is 80mm and traverse step is 75 or 150mm. The mesh connectors have a diameter of 3mm and step of 150mm. The structural plaster should be 25mm thick on both sides with a performance value of < 15 N/mm^2.

Figure 2.6

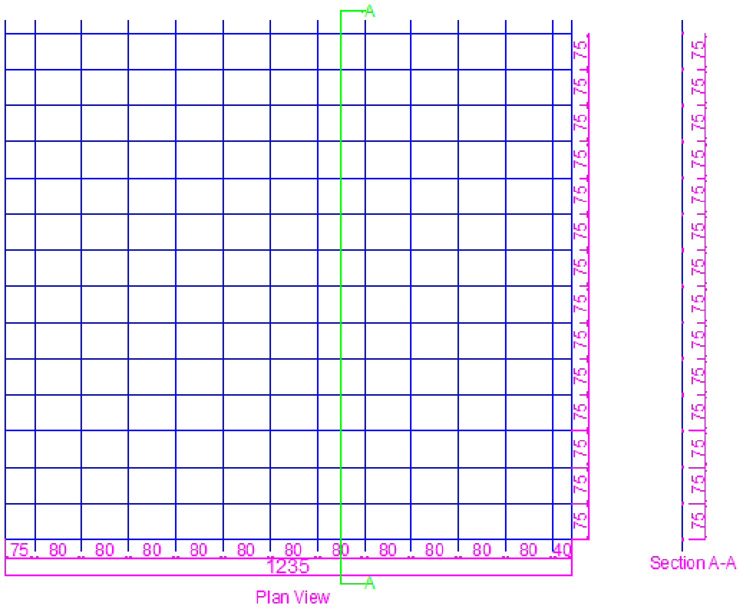


Figure 2.7

2.5.1.3 Single Floor Panel

Used as floors or roofs with spans up to 5m by 5m and supported by the walls in all their sides. The panels are finished on site by 5cm casted concrete in upper side and 3cm of projected plaster in the lower side.

The EPS sheet is 1200mm wide and 80-160mm thick with a wave length of 15mm and a density of 15 Kg/m^3. The mesh is made from galvanised steel with a stress tension value of up to 700 N/mm^2. The mesh is 1235mm wide with longitudinal and traverse wires with a diameter of 2.5-3mm. the longitudinal wire step is 80mm and traverse step is 75mm. The mesh connectors have a diameter of 3mm and step of 150mm. The structural plaster should be 30mm thick on the lower side with a performance value of ≥ 25 N/mm^2 concrete of 50mm thickness is on the upper side with a performance value of ≥ 25 N/mm^2.

Figure 2.8

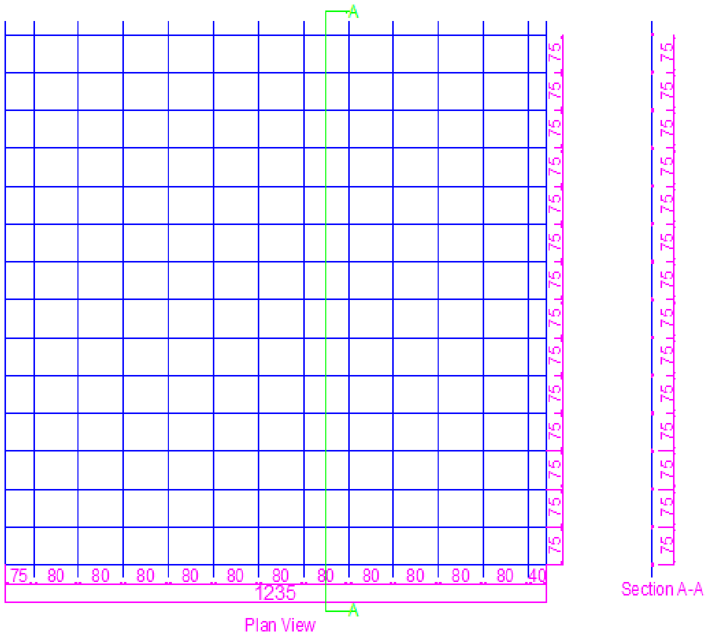


Figure 2.9

2.5.2 Floor Panel

Used as floors or roofs with spans up to 9m. The panels are characterised by the presence of joists. The joists are reinforced on site by steel bars according to the structural verification and they are finished by 4cm of casted concrete in the upper side and 2,5cm of projected plaster in the lower side.

The EPS sheet is 1200mm wide and 160-300mm thick with a joist height of 120-160mm, a wave length of 10mm and a density of 15 Kg/m^3. The mesh is made from galvanised steel with a stress tension value of up to 700 N/mm^2. The mesh is 1235mm wide with longitudinal and traverse wires with a diameter of 2.5-3mm. the longitudinal wire step is 80mm and traverse step is 75mm. The mesh connectors have a diameter of 3mm and step of 150mm. The structural plaster should be 25mm thick on the lower side with a performance value of < 15 N/mm^2 concrete of 50mm thickness is on the upper side with a performance value of ≥ 25 N/mm^2.

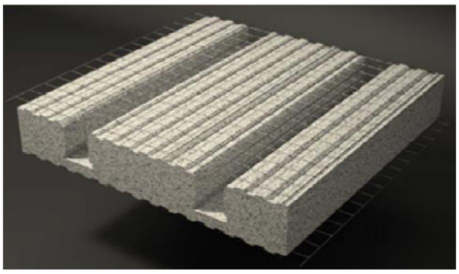


Figure 2.10

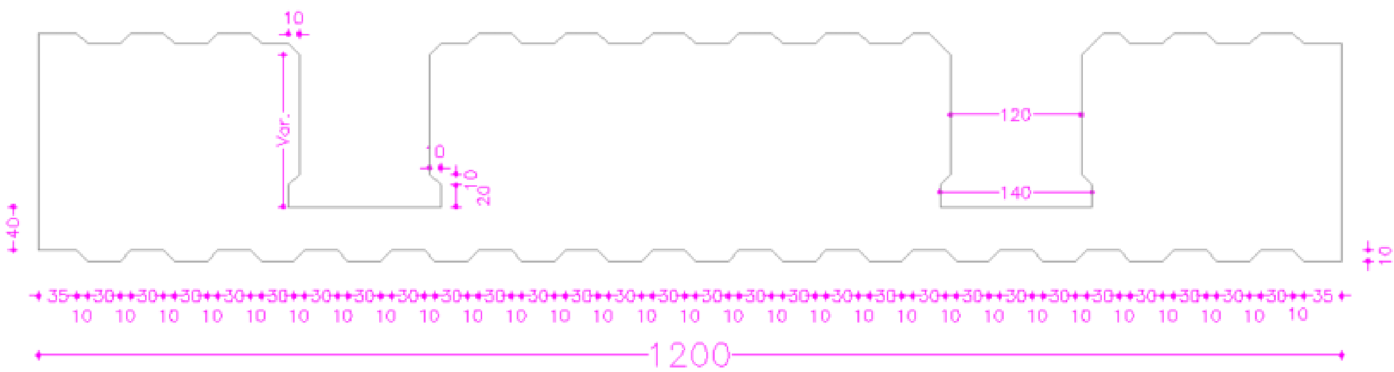


Figure 2.11

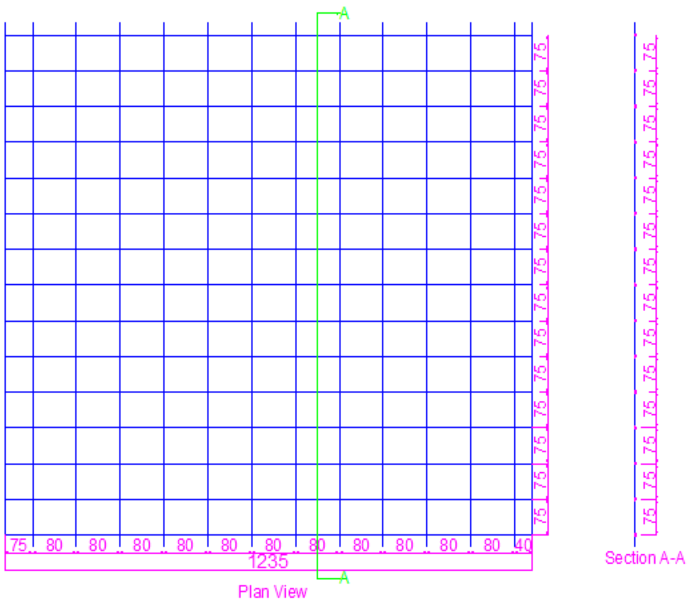


Figure 2.12

2.5.3 Double Panel

Used as a load bearing wall for single and multi-storey buildings. The use limitation of this panel is given only by the structural verifications. This panel consists of 2 single panels connected to each other at a defined distance by some steel connectors welded in electro fusion. Double panel is finished on site casting concrete in the internal gap and projecting non-structural plaster in the external sides.

The EPS sheet is 1200mm wide and 50-100mm thick for every sheet, an internal gap of 80-180mm, a wave length of 15mm and a density of 25 Kg/m^3. Maximum total thickness is 300mm. The mesh is made from galvanised steel with a stress tension value of up to 700 N/mm^2. The mesh is 1235mm wide with longitudinal and traverse wires with a diameter of 2.5-3mm. the longitudinal wire step is 80mm and traverse step is 75mm. The mesh connectors have a diameter of 3mm and step of 150mm. The non-structural plaster should be 20-25mm thick on both sides with a performance value of < 15 N/mm^2. The concrete in the internal gap, has 80-180mm thickness with a performance value of ≥ 25 N/mm^2.

Figure 2.13

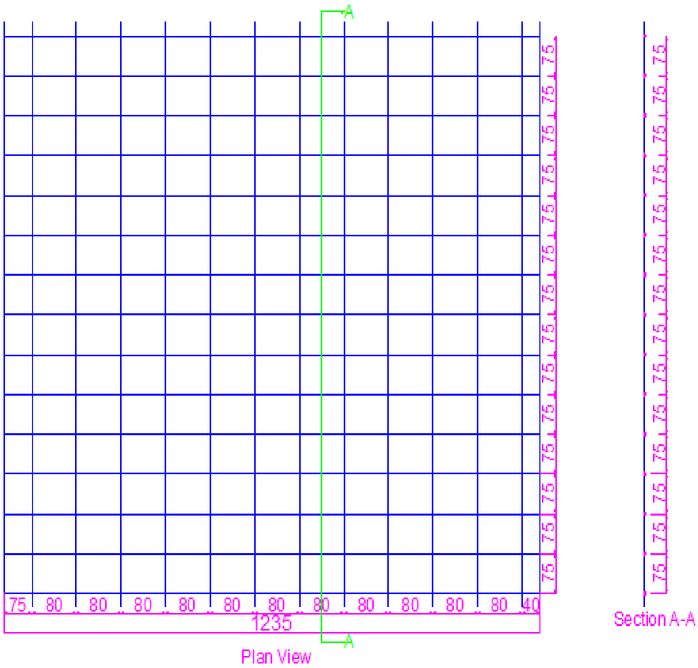


Figure 2.14

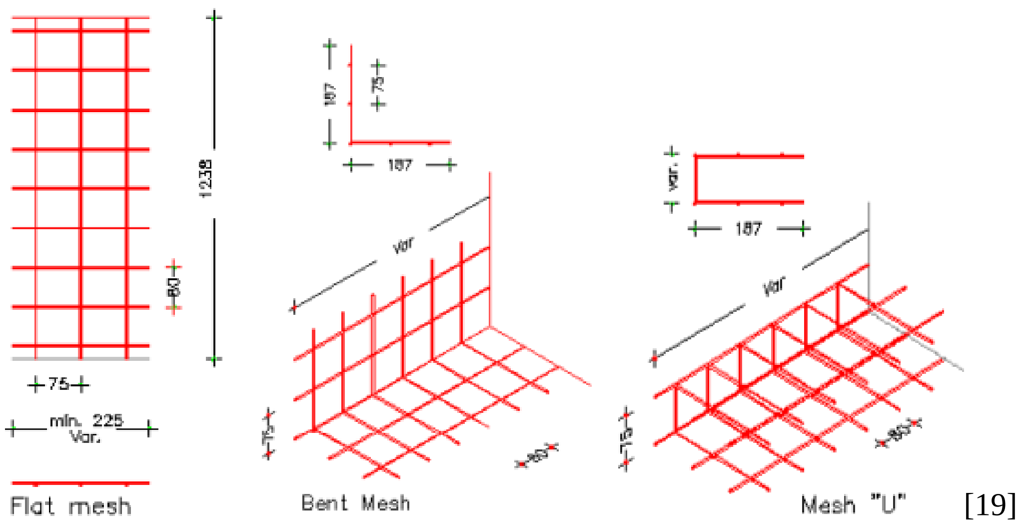
2.5.4 Mesh

The mesh made from galvanised steel is used as reinforcement to carry tensile stress for the EPS panel. It is also used to integrate the whole system together as well as prevent lateral shear of the members.

2.5.4.1 Reinforcement Mesh

The reinforcement mesh is used to reinforce openings and corner- joints between panels so to confer continuity to the structural mesh. Also used to provide extra tensile strength.

- Bent mesh – the bent mesh is used to reinforce the connection in the corners between wall to wall, and wall to slab.
- Flat Mesh – the flat mesh is used to reinforce doors and windows at 45^{o}, to restore where the mesh has been cut and for any joints between panels.
- "U" Mesh – the "U" mesh is used along the perimeter of doors and windows. [19]



[19]

Figure 2.15

Table 2.1 **Structural Elements of the System**

SINGLE PANEL							
	Width (mm)	Thickness (mm)	Wave Length (mm)	Density (Kg/m^3)	Structural Plaster	Non-structural Plaster	Concrete
Load	1200	15-160	15	10-15	35mm (both sides)	-	-

Bearing Wall					$\geq$25N/mm^2		
Partition and cladding walls	1200	40-280	5	10-15	25mm (both sides) <15N/mm^2	-	-
Floor Panel	1200	80-160	15	15	30mm (both sides) $\geq$25N/mm^2	-	50mm (upper side) $\geq$25N/mm^2
FLOOR PANEL							
Joist Height (mm)	Width (mm)	Thickness (mm)	Wave Length (mm)	Density (Kg/m^3)	Structural Plaster	Non-structural Plaster	Concrete
120-160	1200	160-300	10	15	25mm (lower side) <15N/mm^2	-	50mm (upper side) $\geq$25N/mm^2
DOUBLE PANEL							
Internal Gap (mm)	Width (mm)	Thickness (mm)	Wave Length (mm)	Density (Kg/m^3)	Structural Plaster	Non-structural Plaster	Concrete
80-180	1200	50-100	15	25	-	20-25mm (upper &lower side) <15N/mm^2	80-180mm (internal gap) $\geq$25N/mm^2
MESH							
	Width (mm)	Tension Value (N/mm2)	Longitudinal and Traverse Wires			Connectors	
			Diameter (mm)	Longitudinal step (mm)	Traverse step (mm)	Diameter (mm)	Step (mm)
All panels	1235	700	2.5 – 3	80	75	3	150

The structures erected with panels, both single and double, can be represented as bearing wall structures and for this reason, it is necessary that the structure is characterized by:-

- Continuity in elevation- the load bearing walls must continue from the foundation up to the roof, to be able to discharge the loads in a correct way.
- Openings – openings should be vertically aligned so that there areas that ensure full continuous presence of bearing elements. For the same reason it isn't recommended to design big openings or facades with ribbon windows.
- Regularity in plan – the load bearing walls have to be well distributed on the plan, so that the structure has a good distribution of the stiffness.

Figure 2.16

2.6 Comparison of Construction Methods

2.6.1 Masonry Method

2.6.1.1 General

Majority of buildings in Kenya were and still are built using the borrowed traditional masonry method i.e. borrowed from the European culture of stone and mortar or brick and mortar method of construction. Most Kenyans are familiar with this method of construction and, along with a number of advantages, there is a deep psychological attachment to masonry construction that has contributed to its continuation as the main building method in Kenya.

2.6.1.2 Method of Construction

This method of construction involves use of stone piled on top of each other with mortar as the adhesive. The stone is extracted from the quarry while the mortar is made from a mixture of sand, cement and water in specified ratios. This then is used to construct the (standard) foundation, walls and partitions of houses. Slabs, beams and columns are then made from reinforced concrete, which is a mixture of sand, cement, aggregates and water of specified ratios to withstand compressive stresses and steel reinforcement bars to withstand tensile stresses, with regards to design requirements.

Advantages

i. As the most common form of house construction, there are plenty of tradesmen and specialist knowledge available
ii. Materials are readily available
iii. Provides good fire protection
iv. Flexible in design and construction
v. Materials are strong, durable and long lasting
vi. Easy to modify or extend
vii. Once a building has reached the end of its useful lifespan, materials are 100% recyclable.

Disadvantages

i. On-site construction means that work can be affected by adverse weather conditions.
ii. Materials require large on site storage and protection from weather before they are incorporated into the building structure.
iii. On site construction is labour intensive
iv. There are high fluctuating costs of materials
v. High transportation cost
vi. Lengthy construction time
vii. It is not environmentally friendly due to quarrying for stones which leaves the land desolate if it is not rehabilitated.
viii. Demand for cement in the stone and mortar construction method is high, this in turn increases the amount produced to meet the demand. This in turn increases the levels of pollution in the environment in terms of CO_2 production, dust, noise and vibration when operating machinery and during blasting in quarries and damage to land from quarrying.

Figure 2.17

Figure 2.18

2.6.2 EPS Technology

2.6.2.1 General

As earlier stated, EPS is used in the building and construction industry and huge quantities are utilized to make insulation foam for walls, roofs and floor insulation. EPS has also found uses in road construction, bridges, swimming pools, retaining walls, basements and construction of sound proof rooms. In Kenya, EPS has found use in construction of building structures. Currently, there are projects in Ruai, for police quarters being built using the technology. Houses in Muthaiga as well as in Balozi have been constructed using the same technology.

2.6.2.2 Method of Construction

Panels are first prefabricated in the factory. The raw materials are imported and used to manufacture the expanded polystyrene beads which are then moulded into EPS blocks. Different panels are then cut from the blocks and galvanised steel mesh attached to both sides. These panels once ready, are taken onsite to be assembled, and shotcrete or concrete, depending on the panel used, is then used to sandwich and cover the panels, forming a monolithic structure.

Advantages

i. It is a fast method of construction hence reduces construction time
ii. Lightweight-it is composed of roughly 95% of air.
iii. High load bearing capacity at low weight.
iv. Reduction in number of labourers required in construction process
v. Applicable for mass construction
vi. It is 3.5 times stronger than stone, more durable and long lasting
vii. Environmentally friendly
viii. Moisture resistant
ix. Ease of use
x. Cost effective
xi. Reduction on construction waste
xii. Materials are recyclable
xiii. Suitable for use in earthquake prone areas
xiv. Good thermal mass
xv. Sound insulation

Disadvantages

i. Jobs may be lost due to reduced number of labourers required
ii. Need for specialized equipment

Figure 2.19 Finished EPS sample house at NHC factory

EPS is still yet to make a breakthrough in the Kenyan market. With increased help from the government who have implemented a law stating that 30% of current construction of structures should use EPS technology, the housing sector shall see great improvement in solving the nationwide housing deficit crisis.

2.7 Expected Strength Required for Panels

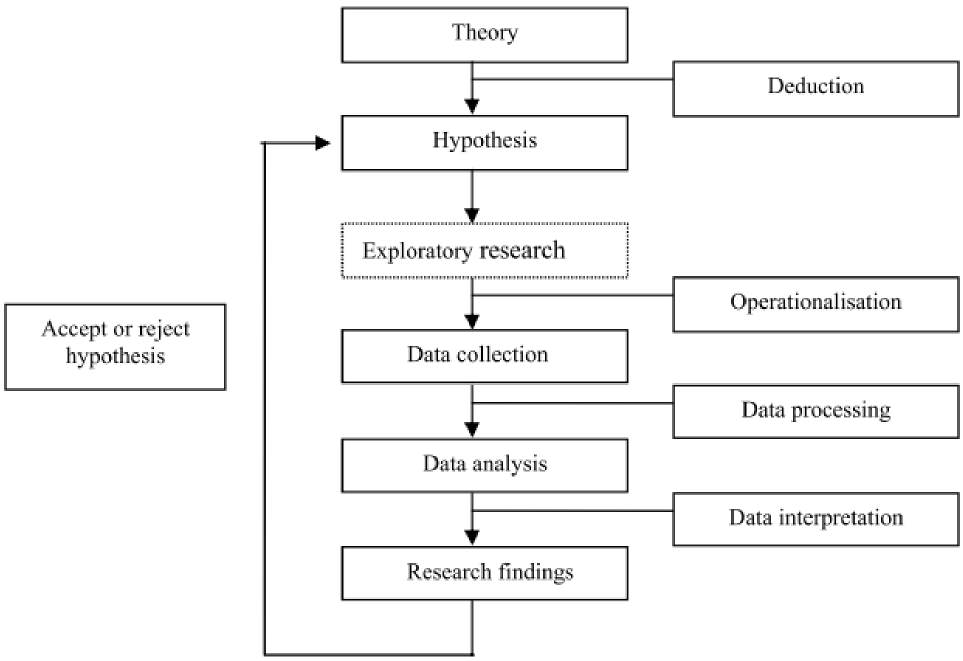
Compressive strength: Ranges from 0.07-0.25 N/mm^2, according to type and product; method of test, BS EN 826.

Bending strength: Ranges from 0.115-0.35 N/mm^2, according to grade and product; method of test BS 4370: Part 1, method 3.

Methodology

3.1 Introduction

Considering the objectives and hypothesis, this research is a small scale research performed to investigate the possibilities of undertaking a larger research study; to decide if it is feasible to do a detailed investigation.



[20]

Figure 3.1 The place of the own research in the hypothesis testing approach to research

3.2 Data Collection Methods

1. Visit to the National Housing Corporation in Mavoko, where expanded polystyrene is manufactured, to find out more about the technology and machines used to manufacture the material as well as process of manufacturing.

2. Approached a contractor, an engineer and a quantity surveyor for an interview with questionnaires about the EPS technology. The number of people given the questionnaire was limited because I could only obtain information from people who had knowledge on the EPS technology.
3. Researched on the internet about information on what had been researched before about the technology and data collected.

3.3 Description of Questionnaires

All questionnaires were administered and dropped off in person. The process of answering the questionnaire intertwined with a short interview with the mentioned professionals..

To the Contractor

The questionnaire consisted of thirteen questions in reference of their experience from using EPS technology in construction.

1. Apart from the conventional brick and mortar method of construction, which other methods of construction have you used or adopted, where and why?
2. Why would you prefer to build with EPS rather than conventional stone masonry method?
3. To build a standard 2 storey house, how much estimated time would it take to build it from start to finish (foundation to roofing, to the inside and outside finishing as well as plumbing and electrical fittings) using EPS and conventional method?
4. List the number of workers required to build the above stated scenario as compared to the conventional method of building.
5. Compare labour costs of EPS and conventional method of building.
6. Does one achieve reduced transportation cost using EPS panels for construction? If yes, state how. If no, state why
7. When did you start using EPS as a construction material and what sparked the interest to start using it here in Kenya?
8. What challenges have you encountered and which ones have you overcome so far since you began using the EPS material?
9. What are the current challenges you face, as a contractor, in using the EPS technology as compared to conventional construction methods?

10. What efforts has the government started in making use of EPS housing spread in the country? What more could the government do to grow the construction industry through EPS housing system?
11. What future do you see for alternative construction material use in Kenya, especially for EPS?
12. What are you general/personal views on the construction industry's acceptance of the same, with reference to engineers, architects, fellow contractors and the general public who form prospective clients?
13. What is the cost comparison for a standard 2 storey house built using EPS and conventional masonry system? How could the cost of EPS system be reduced further in order to be even more competitive?

To the Engineer

As part of achieving the first objective, I used a questionnaire to collect data needed. The questionnaire consisted of eleven questions in reference to use of EPS technology in construction

1. What properties make EPS a good construction material?
2. What is shotcrete? Why was shotcrete chosen to be used, and what properties does it have for the desired purpose? In what ratios are the components mixed to achieve shotcrete? Is there an alternative to shotcrete?
3. Have you tested the strength of the load bearing members? If yes, where were the tests done? What tests were done and what were your key interests when testing the material? What standards were required for the test and is it possible to get the methodology and results for the tests carried out?
4. What is the compressive and flexural strength of EPS wall compared to conventional masonry wall?
5. What is the compressive and flexural strength of EPS slab compared to conventional concrete slab?
6. What other structural properties make the EPS walling and slab system better as construction material as opposed to the conventional stone and mortar?
7. How tall can a building built from EPS panels be? Why the stated answer?

8. What modes of failure and defects can be experienced from the use of EPS panels and slab? What leads to these modes of failure?
9. Which building standards in Kenya give guidance on construction using EPS material?
10. Are there major differences in strength when using different EPS technologies from different countries? What are the differences and why did Kenya pick the current technology for manufacturing the panels?
11. Are there any improvements you think can be added to the EPS material produced at the NHC factory?

To the Quantity Surveyor

As part of achieving the second objective, I used a questionnaire to collect the data needed. The questionnaire consisted of 6 questions which helped in determining whether EPS technology is cheaper than the conventional method of construction.

1. When comparing EPS and conventional/traditional brick and mortar method of construction, which one is cheaper?

- EPS technology
- Traditional brick and mortar

2. If EPS is cheaper, what makes it cheaper?

- The cost of material
- Transportation of material
- Number of labourers
- Other

3. If traditional brick and mortar is cheaper, what makes it cheaper than EPS?

- The cost of material
- Transportation of material
- Number of labourers
- Other

4. Do you have a breakdown of how costing was carried out for both methods of construction?

- Yes
- No

5. Is it possible for me to get the information in the above question?

- Yes
- No

6. What can be improved in order to make EPS a cheaper and more affordable method of construction?

3.4 Test Procedures

Optimum performance of a load carrying member is often related to both strength characteristics and resiliency. EPS is easily fabricated to meet specific design and dimensional requirements. Different panels have different varying densities according to Table 2.1. The mechanical strength of EPS varies with its density and due to its design flexibility and versatility, it can be cut into sheets, slabs and design requirements to meet specific building code standards.

Tests carried out cover the determination of the breaking load and calculated flexural strength of a rectangular cross section of a preformed block type, tested as a single beam.

Material Type

The following types of the materials of EPS tested as defined in BS EN13163 [21]:

i. EPS 70 – density of 15 Kg/m^3
ii. EPS 100 – density of 20 Kg/m^3
iii. EPS 150 – density of 25 Kg/m^3
iv. EPS 200 – density of 30 Kg/m^3
v. EPS 250 – density of 35 Kg/m^3

Additional types are also available for specific applications; for example, types with compressive-stress values, at 10%, of 0.4 and 0.5 N/mm^2.

Shape and size

After moulding, the 'block' material is cut to size and thickness according to the intended end use; see individual product and application data on Table 2.1.

Scope

These test methods cover procedures for the preparation of specimens and testing of mechanical properties of expanded polystyrene.

Sampling

Test specimens shall be taken from the same sample with a total area not less than 1 m^2. The shorter side of the sample shall not be less than 300 mm or a full size of the product, whichever is smaller. [22]

3.5 Compressive Strength

General

The most important property of a structural material which will be covered with concrete is the compressive strength which is determined by loading as dictated by the standards.

Apparatus

The testing machine may be of any type sufficient capacity which will provide the required rate of loading.

Procedure

Preparation of Specimens

- Specimens of dimension 50×50×50mm were cut from the sample.[23]
- Three samples were prepared and all possible measures were taken during preparation of sample, in a similar way to the actual placing conditions in site.

Loading

- Specimens were placed between the bearing blocks on the machine
- They were loaded at a uniform rate of $0.02 N/mm^2$ per second, until failure.
- The maximum load carried by the specimen, was recorded from the machine.

3.6 Flexural Strength

General

Tensile strength is commonly defined in one of the three ways: direct tensile strength, tensile splitting strength or flexural strength. The flexural strength is about 1.5 times the tensile stress determined by splitting test [24]

Flexural strength may be determined by using the two methods:-

I. Test method 1 – A loading system utilizing centre loading on a simply supported beam, supported at both ends

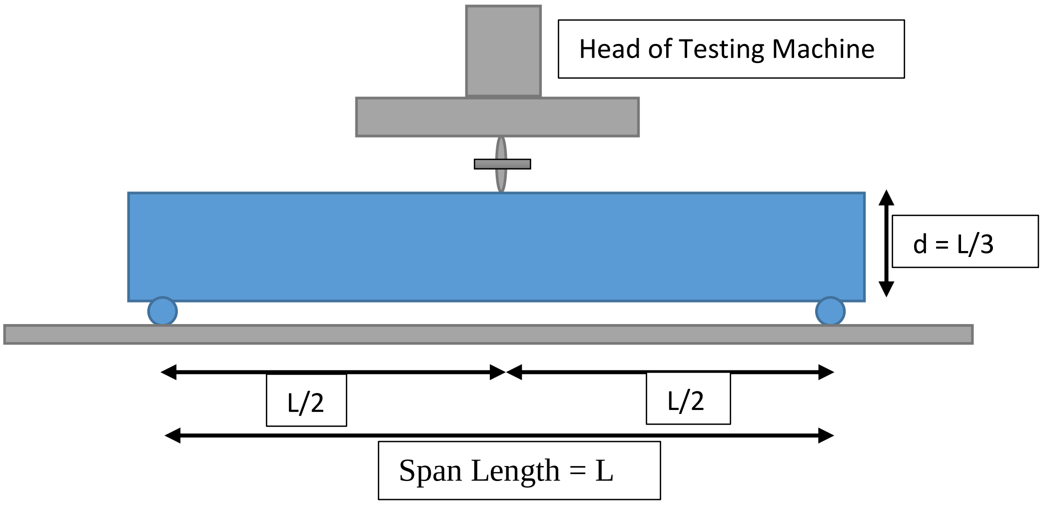


Figure 3.2 Centre Point Loading

I. Test method 2 – A loading system utilizing two symmetric load points equally spaced from their adjacent support joints at each end with a distance between load points.

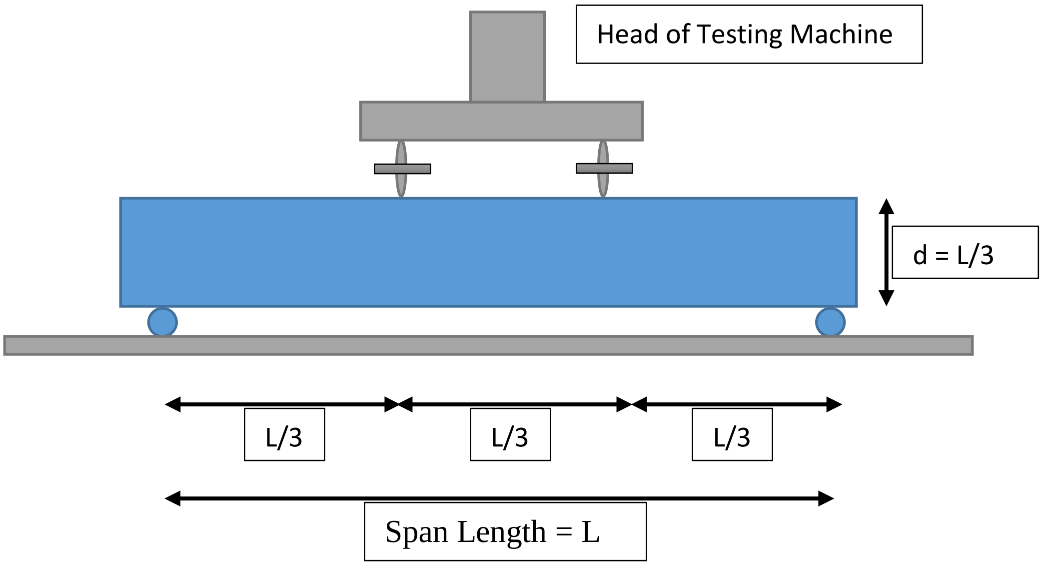


Figure 3.3 Four Point Loading

The specimens and procedures for the two methods are very similar; for this test, method 1 was used.

Apparatus

A loading machine with sufficient capacity and bearing blocks (designed to insure that forces applied to the beam will be vertical only without eccentricity) was used to perform the test.

Procedure

Preparation of specimen

- Specimens of dimension 300×150×50mm were cut from the sample [23]

- Three samples were prepared and all possible measures were taken during preparation of sample, in a similar way to the actual placing conditions in site.

Loading

- The test specimen was centred on the supporting blocks.
- The load-applying blocks were brought into contact with the upper surface at the centre line between the supports.
- The specimen was loaded until point of failure.
- The maximum load at point of rupture was recorded.

Chapter Four

Results

4.1 Introduction

The test results are according to BS EN 13163 – 2001 [21]

Calculations

Compressive strength

The compressive strength of each individual specimen is calculated by dividing the maximum load at failure by the cross-sectional area of the specimen. The average of the three individual compressive strengths was accepted as the compressive strength of the sample.

$$\text{Compressive strength} = \frac{P}{bd}$$

Flexural strength

The modulus of rupture is calculated by:

$$R = \frac{3PL}{2bd^2}$$

Where:

- R = modulus of rupture
- P = maximum applied load at the end of the test
- L = span length
- b = average width of specimen
- d = average depth of specimen

The average of the three individual flexural strength was accepted as the flexural strength of the sample.

4.2 Test Results

Table 4.1 Test Results [21]

Panel Density	15 Kg/m^3	20 Kg/m^3	25 Kg/m^3	30 Kg/m^3	35 Kg/m^3
MECHANICAL PROPERTIES					
Compressive Strength @ 10% compression (N/mm^2)	0.07	0.1	0.15	0.2	0.25
Bending Strength (N/mm^2)	0.115	0.15	0.2	0.25	0.35

4.3 Cost Analysis

Comparison prices per cubic metre between expanded polystyrene technology and traditional method of construction.

4.3.1 Materials

Table 4.2 NHC-EPS Factory Panels Price List

MEASUREMENT 3m x 1.2m	WEIGHT (Kg)	SALE PRICE (Ksh) 27th November 2013
Single Panels 60mm thick	15.4	5,371
Single Panels 80mm thick	16.2	5,681
Double Panels 60mm thick	32.2	8,849
Floor Panels 200mm thick	34.6	9,433
Floor Panels 150mm thick	19.2	6,367
Wall flat mesh	1.8	627
U-mesh 80mm wide	2.4	766
Wall Angle mesh	1.8	690
Wall Angle mesh	2.2	728

Table 4.3 The Joint Building Council Price List

ITEM	PRICE (August 2013)
Cement in bags (1442kg/m^3)	20,677/- per m^3
Sand	3,133/- per m^3

Table 4.4 Contractors Average All-In-Rates and Cost

ITEM	PRICE (December 2013)
Concrete 1:2:4 (class 20/20)	11,400/- per m^3
Mild Steel 16mm diameter	150/- per Kg
Natural quarry stone walling 100mm thick	1,200 per m^2

Note: All prices stated above are inclusive of 16% VAT

Labour costs

- Skilled Labourer for one day: 1,000 Ksh per day
- Non-skilled labourer for one day: 500 Ksh per day

4.3.2 Calculations

Table 4.5 Cost of expanded polystyrene technology

ITEM	Price (Ksh)	Price (Ksh) per square metre
Single panel 60mm	5,371	1,491.94
Structural Plaster	11,400	798
1 skilled labourer	1,000	1,000
1 non skilled labourer	500	500
Total		3,789.94 ≈ 3,790
10% additional cost of total cost for contingencies		379

Final Total	4,169

Table 4.6 Cost of traditional stone and mortar method of construction

ITEM	Price (Ksh)	Price (Ksh) per square metre
Natural quarry stone walling 100mm thick	1,200	1,200
Sand	3,133	50.13
Cement	20,677	110.27
2 skilled labourers	1,000 each	2,000
2 non skilled labourers	500 each	1,000
Total		4,460.4 ≈ 4,460
10% additional cost of total cost for contingencies		446
Final Total		4,906

Chapter Five

Discussion

Expanded Polystyrene has been approved by British Standards [21] for use as a construction material. This follows the tests carried out and results received from the tests. Normal compressive and flexural strength of different concrete grades are as shown in the table below.

Table 5.1 Compressive and Flexural Strength of Different Concrete Grades

Grade of Concrete	Tensile strength N/mm^2 [25]	Specified characteristic compressive strength (N/mm^2) [25]
C15	2.4	16
C20	2.9	20
C25	3.3	25
C30	3.8	30
C35	4.3	37
C40	4.8	45
C45	5.3	50

Given the low strength of expanded polystyrene as compared to the concrete strength in table 5.1, EPS is mainly used as a filler material in construction. The thickness of the panel provides the structural member with high bending stiffness with an overall low density. This type of composite construction, once bound together strongly, acts as a single unit from a structural point of view.

In table 4.1, the compressive and flexural strength of EPS increases with increase in density. Showing that the higher the density, the stronger the material. It is also noted that the flexural strength of the panel is higher than the compressive strength. This indicates that the panel is capable of carrying tensile stresses, though by a small quantity, better than compressive. From table 5.1, it is clear that concrete has high compressive strength and low tensile strength. The expanded polystyrene technology therefore comes at an advantage, especially after adding mesh to the panels to act as reinforcement, in the whole structural system.

Galvanised steel, used to make the mesh for the panel, has a characteristic yield strength of $250N/mm^2$ [26]. This then offers the member added tensile strength.

The cost analysis stage involved analysis of two construction methods in comparison with each other. For construction of a square meter of wall using expanded polystyrene technology, material costs were 2,290/- and labour costs 1,500/- with an additional 10% of total cost for contingencies, totalling to 4,169/- . For construction of a square meter of wall using stone and mortar method, material costs were 1,360/- and labour costs 3,000/- with an additional 10% of total cost for contingencies, totalling to 4,906/-

Chapter Six

Conclusion and Recommendation

6.1 Conclusion

The first task of the field study was to determine the suitability of using expanded polystyrene technology in construction. The tests for the compressive and flexural strength, as well as use of expanded polystyrene as a filler material proved that that technology can be used for structural purposes.

The second task of the field study involved evaluating the cost of using expanded polystyrene as a construction material. A comparison was made between the prices of using EPS technology and using the conventional stone and mortar method. The evaluation mainly concentrated on the material cost as well as labour cost as aspects that greatly influence the total cost of construction. The cost of materials while using the EPS technology proved to be more expensive than using the conventional stone and mortar for wall construction. But since the conventional method of construction is more labour intensive, labour proved to be more costly than using EPS technology. EPS thus proved to be a cheaper method of construction.

The hypothesis has thus been proven showing that expanded polystyrene technology can provide a low cost solution to the national housing deficit in the country.

6.2 Recommendations

The results for compressive and flexural strength were satisfactory. Though further assessment should be carried out to evaluate aspects such as

i. Improved tying of meshes at joining panels to assist in shear loading
ii. Improved carrying of eccentric loads.

To educate the public about use of EPS in order to help them embrace the new technology and use it in building construction.

To eliminate factors that make the current price of the panels expensive such as:-

i. Importing the pre-expanded beads

   Importing the beads gives rise to extra costs such as taxation to material into the country as opposed to locally available materials like stones and bricks. It would be cheaper if the beads were manufactured here in Kenya, and better yet, from our own oil in Turkana.

ii. Only one manufacturing company for the panels

   National Housing Corporation currently has a panel manufacturing company in Mavoko. Being the only company manufacturing the panels, there currently aren't any competitor prices that can effectively lower the market price of the panel or offer a lower price for the panel.

References

[1] Basic Needs; *http://en.wikipedia.org/wiki/Basic_needs*
January 22, 2014

[2] Demographics of Kenya; *http://en.wikipedia.org/wiki/Demographics_of_Kenya*
January 24, 2014

[3] Rural poverty in Kenya; *http://www.ruralpovertyportal.org/country/home/tags/kenya*
January 27, 2014

[4] A history of missed opportunities housing Kenyans;
http://www.standardmedia.co.ke/?articleID=2000086816&story_title=a-history-of-missed-opportunities-housing-kenyans&pageNo=2
January 27, 2014

[5] Population, Climate Change and Sustainable Development in Kenya; *http://populationaction.org/wp-content/uploads/2013/01/Kenya_PIB_Final.pdf*
January 24, 2014

[6] The New Times: Kenya to host regional housing expo; *http://www.newtimes.co.rw/news/index.php?i=15101&a=57750*
January 25, 2014

[7] Sabahi: Kenya looks to private sector to curb housing shortage; *http://sabahionline.com/en_GB/articles/hoa/articles/newsbriefs/2012/03/23/newsbrief-08*
January 22, 2014

[8] The Star: What hinders supply of low income housing in Kenya; *http://www.the-star.co.ke/news/article-14657/what-hinders-supply-low-income-housing-kenya*
January 27, 2014

[9] Housing crisis in Nairobi to worsen by Mwakilishi
http://www.mwakilishi.com/content/articles/2012/10/20/housing-crisis-in-nairobi-to-worsen-experts-warn.html
January 22, 2014

[10] Business Barbados: What Really Drives Construction Cost
http://businessbarbados.com/industries/construction/what-really-drives-construction-cost/
January 30, 2014

[11] The Plastics Portal: Expanded Polystyrene (EPS). Expert: Eric Faes;
http://www.plasticseurope.org/what-is-plastic/types-of-plastics-11148/expanded-polystyrene.aspx
February 20, 2014

[12] ICF Builder Magazine: “History of ICFs”
http://www.icfmag.com/articles/features/history_of_icfs.html
March 7, 2014

[13] *NASCA Construction Limited: Menelik K. Makonnen*
February 26, 2014

[14] Construction Business Review: Italian building technology makes its way to Kenya by John Ndurie; *http://www.constructionkenya.com/2836/italian-building-technology-makes-it-way-to-kenya/*
February 20, 2014

[15] Construction Business Review: Home developers urged to build more affordable homes by Helen Ndaiga; *http://www.constructionkenya.com/2016/home-developers-urged-to-build-more-affordable-homes/*
February 20, 2014

[16] Foam Fabricators: What is EPS?; *http://foamfabricatorsinc.com/Page.aspx?nid=118*
February 21, 2014

[17] ACH Foam Technologies: EPS Manufacturing Process; *http://www.achfoam.com/EPS-Manufacturing.aspx*
February 19, 2014

[18] Barnes: Manufacture; *http://www.barnesplastics.co.nz/Environment_Manufacture.html*
February 21, 2014

[19] *Schnell Home: A Schnell Training Presentation.pdf*
March 6, 2014

[20] The influence of national culture on the structure of tourism organisations. Examples from France and Switzerland; *http://www.du.se/pagefiles/5050/etm%20thesis%20careil.pdf*
March 19, 2014

[21] Jabelite Intelligent Insulation; *http://www.jablite.co.uk/site/datasheets/3/3.pdf*
March 19, 2014

[22] *BS EN13163*; 5 Test methods: – 5.1 Sampling
March 20, 2014

[23] *BS EN13163*; Table 13 – Test methods, test specimens and conditions
March 20, 2014

[24] The Constructor Civil Engineering Home by Gopal Mishra; *http://theconstructor.org/concrete/tests-on-hardened-concrete-in-structures/7228/*
March 24, 2014

[25] Properties of Concrete for use in Eurocode 2 by P.Bamforth, D.Chisholm, J.Gibbs, T.Harrison;*http://www.sefindia.org/forum/files/properties_of_concrete_for_use_in_eurocode_2_135.pdf*
March 27, 2014

[26] The online metals guide to steel; *http://www.onlinemetals.com/steelguide.cfm*
March 26, 2014

Appendices

Questionnaires

TO CONTRACTOR

1. Apart from the conventional brick and mortar method of construction, which other methods of construction have you used or adopted, where and why?
2. Why would you prefer to build with EPS rather than conventional stone masonry method?
3. To build a standard 2 storey house, how much estimated time would it take to build it from start to finish (foundation to roofing, to the inside and outside finishing as well as plumbing and electrical fittings) using EPS and conventional method?
4. List the number of workers required to build the above stated scenario as compared to the conventional method of building.
5. Compare labour costs of EPS and conventional method of building.
6. Does one achieve reduced transportation cost using EPS panels for construction? If yes, state how. If no, state why
7. When did you start using EPS as a construction material and what sparked the interest to start using it here in Kenya?
8. What challenges have you encountered and which ones have you overcome so far since you began using the EPS material?
9. What are the current challenges you face, as a contractor, in using the EPS technology as compared to conventional construction methods?
10. What efforts has the government started in making use of EPS housing spread in the country? What more could the government do to grow the construction industry through EPS housing system?
11. What future do you see for alternative construction material use in Kenya, especially for EPS?
12. What are you general/personal views on the construction industry's acceptance of the same, with reference to engineers, architects, fellow contractors and the general public who form prospective clients?

13. What is the cost comparison for a standard 2 storey house built using EPS and conventional masonry system? How could the cost of EPS system be reduced further in order to be even more competitive?